

Ionization states of anomalous cosmic ray nitrogen to neon ions in Spacelab-3 Anuradha experiment

Banashree Mitra, S Biswas, N Durgaprasad, R K Singh and M N Vahia

Tata Institute of Fundamental Research, Bombay-400 005, India

and

A Dutta and J N Goswami

Physical Research Laboratory, Ahmedabad-380 009, India

Abstract : The ionization states of anomalous cosmic rays were measured in this experiment by means of a time resolution device providing information of the arrival location and direction of the particle impinging on the detector system. Here we present the results of the ionization states of anomalous cosmic ray in the energy interval 10 – 50 MeV/n achieved by two methods. In one method, the trajectory computation of anomalous cosmic rays shows their ionization states as +1 or +2. In the second method, the charge state determination is computed only for oxygen nuclei. The orbit average oxygen flux is consistent with the ionization state +1, as observed by the first method. Thus, the two methods yield the same result.

Keywords : Cosmic rays, Anuradha experiment, ionization states.

PACS Nos : 94.40. i, 94.80. + g

1. Introduction

The discovery of some new kind of low energy cosmic ray particles in 1973/74 by various space probes near earth shows the strikingly different behaviour to that of the hitherto known galactic cosmic rays (GCR). The flux of these particles mostly consists of helium, nitrogen, oxygen and neon nuclei and were observed to be enhanced in the energy range 10 – 100 MeV/n, as compared to GCR. The unusual behaviour of these particles, e.g. radial gradient, solar modulation, composition, etc. and lack of knowledge about these led to classify them as Anomalous Cosmic Rays (ACR). The origin, acceleration and propagation mechanisms of the ACR are unknown. Several authors have put forward several theories to correspond to their composition, properties, etc. To establish these theories, one needs to have a knowledge of their ionization state. The Anuradha experiment was specially designed to determine the ionization state of ACR. The experiment has made use of the solid state nuclear track detector (SSNTD) CR-39 (DOP). It was flown at a height of 350 km with orbital inclination of 57° during April 29 – May 6, 1985

(Biswas et al 1986). Here we report the ionization state of ACR nitrogen, oxygen, and neon ions obtained in this experiment.

2. Experiment

The detector module is composed of the most sensitive and efficient SSNTD CR-39 (DOP). The charge resolution of this detector is less than unit charge. A schematic diagram of the detector system is given in Biswas et al (1988). The upper dome is an alloy of aluminium and mylar of thickness 24 mg/cm^2 , so that a minimum energy of 10 MeV/n can be recorded for oxygen. The stack of detectors which are circular in shape with 40 cm dia has two parts—one part comprises of only one sheet of the detector while the other part below this, comprises of 175 sheets of CR-39 and few Lexan sheets in between, with a total thickness of 4.5 cm . The top part is kept fixed in position while the whole of the bottom part, at a distance of $500 \text{ }\mu\text{m}$ from it, is rotated with a stepper motor in steps of 40 arc secs in 10 secs .

The charge calibration of the detector was carried out using $140 \text{ MeV/n Fe}^{56}$ beam from Berkeley Bevalac, USA, to which the detectors were exposed. Measurements of these tracks give us ionization rate (V_T/V_G) vs, residual range for Fe^{56} . Now, with the help of the relation derived by Henke and Benton (1971) between REL, energy and range we have derived the calibration curve for other nuclei down to $Z=6$. It is shown in the Figure 1 with some tracks plotted on it for identification. Details of this procedure is described in Biswas et al (1988).

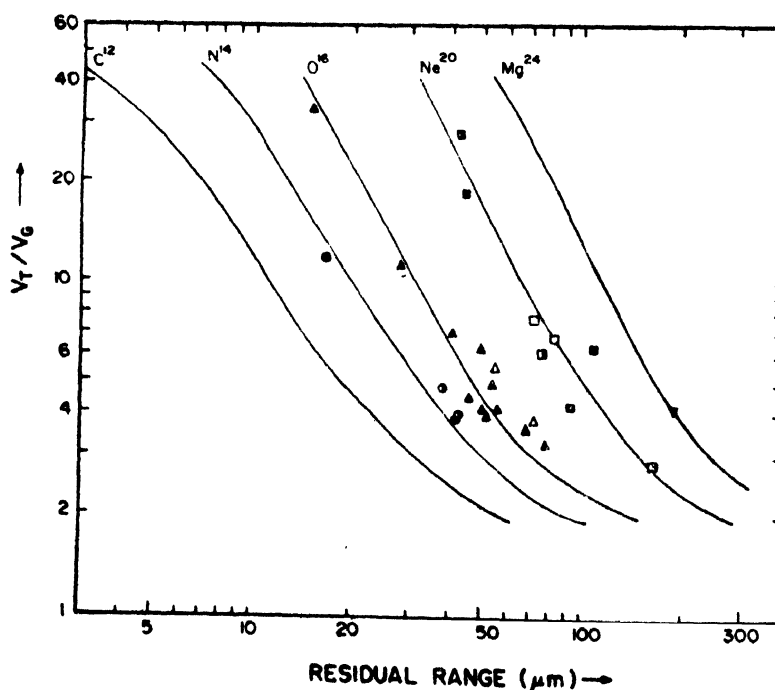


Figure 1. Calibration curves for N^{14} to Mg^{24} with events plotted.

3. Results and discussion

The measurement of ionization state can be carried out by two methods :

(1) Orbit average flux method, and (2) Trajectory computation method.

3.1. Method 1 :

Tracks for $Z \geq 7$ were scanned and measured in the four sheets of areas 200, 161, 276 and 125 sq. cm respectively, and obtained 3 oxygen tracks in the energy range 16–19 MeV/n, 5 in the energy range 20–26 MeV/n and 3 in the energy interval 35–55 MeV/n. With these identified events, the orbit average fluxes of ACR oxygen are obtained using the total exposure time of 5.18×10^5 sec and the effective solid angle which is 0.88 sr. instead of 3.14 sr. This is because of the obscurations by the earth's shadow and the module. The orbit average fluxes of ACR oxygen calculated are :

$(2.5 \pm 1.4) \times 10^{-4}$ particles/[m². sr. sec. (MeV/n)] at energy $E = 17.5$ MeV/n

$(2.9 \pm 1.3) \times 10^{-4}$ particles/[m². sr. sec. (MeV/n)] at energy $E = 23.0$ MeV/n

$(7.3 \pm 4.2) \times 10^{-5}$ particles/[m². sr. sec. (MeV/n)] at energy $E = 45.0$ MeV/n

These measured fluxes are to be compared with the computed ACR oxygen flux inside the magnetosphere from space probe data. Voyager 2 has measured the ACR oxygen flux during the same epoch of SL-3 flight but at 17 AU. The correction for radial gradient is applied making use of the relation

$$\ln (F_1/F_2) = G_r(r_1 - r_2)$$

where F_1, F_2 are the fluxes at two different locations r_1 and r_2 respectively and G_r , being the radial gradient which is found to be 15 %/AU from 1–17 AU measured by Cummings and Stone (1987).

The effective exposure factors are then calculated, from which we obtain geomagnetic transmission factors for different assumed ionization states. The orbit averaged flux of oxygen inside the magnetosphere is then obtained for a particular ionization state as

Orbit average flux of energy ΔE inside the magnetosphere =

(interplanetary flux of energy ΔE) \times (effective exposure factor for rigidity ΔR)

where ΔR is the rigidity interval corresponding to the energy interval ΔE .

Comparison of these fluxes with that of measured flux in Figure 2 yields the average ionization state of ACR oxygen as +1.

3.2. Method 2 :

In this method, we make use of the rotational mechanism of the lower stack. As shown in Figure 3, a charged particle will leave a trace of its path along subsequent sheets depending on its energy. In Figure 3, ST defines that the particle has single

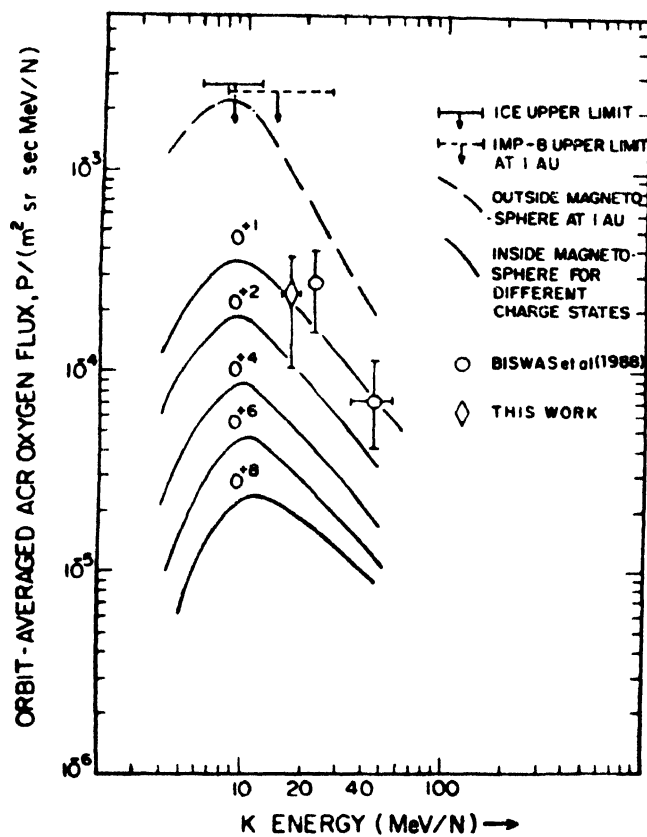


Figure 2. Measured and calculated orbit averaged ACR oxygen flux.

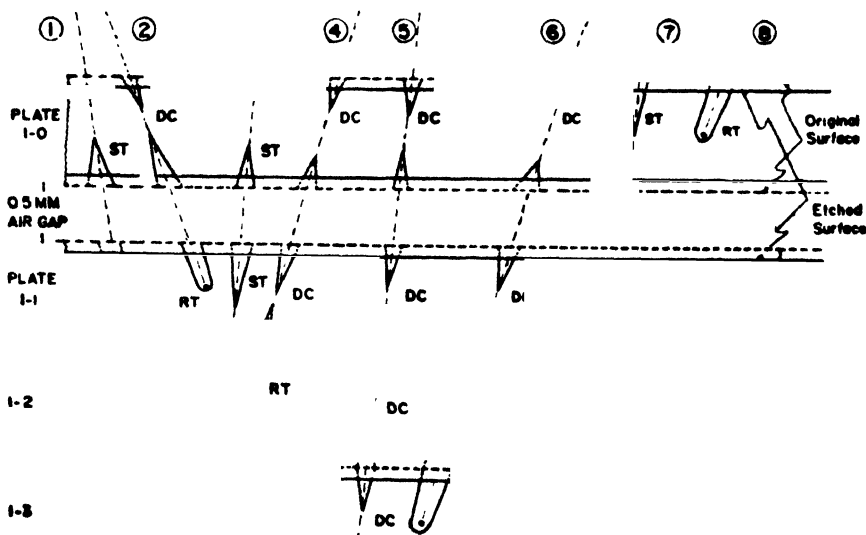


Figure 3. Different types of cones formed when a charged particle passes through a stack of detectors.

track in that sheet with a sharp tip where as DC defines that it has double cones-one at the entry surface and the other at the exit surface. RT is defined as when a particle comes to rest and it is etched for much longer time, the end becomes a rounded one and hence round tip or RT. JDC are these DC which are longer than at least half of plate thickness and overlap with each other. The parameters of the tracks such as length, minor axis, depth, dip angle, azimuth position, etc. are measured for each of the track segments in the stationary sheet and also in the rotating bottom stack. The track segment from the upper one is matched with that of the lower one using appropriate algorithm. They are then followed to their stopping point which provides us with the particle identification, its range and consequently energy with which it impinges on the detector. The encoder reading difference between the matched segments provides with the arrival time information which, in turn, is converted into spatial distribution such as latitude, longitude, altitude and arrival direction in space. With all these information in hand, trajectory computation of each particle is carried out in the geomagnetic field with multipole expansion of 1985 epoch (Shea and Smart 1986) yielding the threshold rigidity R of that particular ion. The ionization state is then obtained using the relation

$$Z^* = \frac{APc}{R}$$

A being the atomic mass, P the particle's momentum/nucleon and c , the velocity of light.

The Table 1 shows the ionization state of ACR ions with their energy and computed threshold rigidity.

Table 1. Charge state of anomalous cosmic rays.

ion	Energy (MeV/n)	Total momentum (GeV)	Threshold rigidity (GV)	Upper limit of Z^*
N ¹⁴	14.8	2.34	1.30	1.8
N ¹⁴	14.6	2.33	0.75	3.1
O ¹⁶	17.4	2.90	1.45	2.0
O ¹⁶	17.8	2.94	1.50	2.0
O ¹⁶	16.2	2.80	2.25	1.2
O ¹⁶	15.7	2.76	2.30	1.2
Ne ²⁰	17.7	3.66	2.7	1.4
Ne ²⁰	17.7	3.66	3.5	1.0
Ne ²⁰	25.5	4.40	3.2	1.4
Ne ²⁰	17.5	3.64	1.9	1.9
Ne ²⁰	20.3	3.93	3.1	1.3

5. Conclusion

The results indicate that the ACR oxygen, nitrogen, neon events are of singly ionized state or consistent with singly ionized state. This result supports the theory forwarded by Fisk et al (1974) that the ACR are originated from the interstellar neutral particles streaming into the heliosphere, and get singly ionized by solar ultraviolet radiation. The theory requires that they should be only singly ionized. Further investigations are carried out in this field.

References

- Biswas S, Chakrabarti R, Cowsik R, Durgaprasad N, Kajarekar P J, Singh R K, Vahia M N, Yadav J S, Dutta N, Goswami J N, Lal D, Mazumdar H S, Subhedar D V and Padmanabhan M K 1986 *Pramana* **27** 89
- Biswas S, Durgaprasad N, Mitra Banashree, Singh R K, Vahia M N, Yadav J S, Dutta A and Goswami J N 1988 *Astrophys Space Sci.* **149** 357
- Cummings A C and Stone E C 1987 *Proc. 20th Int. Cosmic Ray Conf. (Moscow)* **3** 421
- Fisk L A, Kozlovsky B and Ramaty R 1974 *Astrophys. J.* **190** L 35
- Henke R P and Benton E V 1971 *Nucl. Instrum. Meth.* **97** 483
- Shea M A and Smart D 1986 (Private Communication)